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HOT HARDNESS CHARACTERISTICS OF AUSFORMED AISI M-50, MATRIX II, WD-65, MODIFIED AISI 440-C, AND SUPER NITRALLOY

by James L. Chevalier, Marshall W. Dietrich, and Erwin V. Zaretsky

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HOT HARDNESS CHARACTERISTICS OF AUSFORMED AISI M-50, MATRIX II, WD-65, MODIFIED AISI 440-C, AND SUPER NITRALLOY

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SUMMARY

Short-term hot hardness studies were performed with ausformed AISI M-50, Matrix II, WD-65, modified AISI 440-C (14-4-1), and case hardened Super Nitralloy. Hardness levels of each material were measured at elevated temperatures in an electric furnace with a low oxygen environment. Test temperatures ranged from 294 to 877 K (70° to 1120° F).

The hot hardness characteristics of the ausformed AISI M-50, Matrix II, WD-65, and modified AISI 440-C were the same as those determined for high-speed tool steels. Hot hardness for these steels can be predicted within one point Rockwell C. The hot hardness characteristics of both the case and core of Super Nitralloy were superior to AISI 52100 but inferior to the high-speed tool steels. The short-term Rockwell C hardness at temperature for the Super Nitralloy material between 294 and 769 K (70° and 925° F) can be predicted within one point Rockwell C.

INTRODUCTION

In recent years, tool steels have been used with increasing frequency as rolling-element bearing materials for service above 450 K (350° F) in applications such as turbojet engines. In these applications, dimensional stability, retention of hot hardness, wear resistance, and oxidation resistance at elevated temperatures are particularly important. Typical of these high-speed steels are AISI M-1, M-2, M-10, M-50, and Halmo. These alloys contain elements such as molybdenum, tungsten, and vanadium, which are all strong carbide formers. The carbides that form not only provide increased hardness of the material but also help to retain this hardness at elevated temperatures. These materials are through-hardenable steels. That is, material hardness is attained throughout the part by heat treatment rather than by a case hardening procedure such as carburizing or nitriding.

In a previous investigation (ref. 1), short-term hot hardness studies were performed with AISI 52100, AISI M-1, AISI M-50, Halmo, and WB-49. Based upon the criterion of a minimum Rockwell C hardness of 58 for rolling-element systems, the limiting temperatures of all the materials studied were dependent on initial room temperature hardnesses and tempering temperatures. For the same initial room temperature hardness, the short-term hot hardness of AISI M-1, AISI M-50, Halmo, and WB-49 are identical from 294 to 812 K (70° to 1000° F) and independent of material composition.

The short-term Rockwell C hardness at temperature for the materials studied can be determined within one point Rockwell C (Rc) from the following equation derived in reference 1:

$$(Rc)_T = (Rc)_{RT} - \alpha \, \Delta T^{\beta}$$

where

$(Rc)_T$	Rockwell C hardness at operating temperature
$(Rc)_{RT}$	Rockwell C hardness at room temperature
ΔT	change in temperature, $T_T - T_{RT}$, K; $^{\circ}F$
T_{RT}	room temperature, K; $^{\circ}F$
T_T	operating temperature, K; $^{\circ}F$
α	temperature proportionality factor, $(K)^{-\beta}$; $(^{\circ}F)^{-\beta}$
β	exponent

This equation form is valid for AISI 52100 from 294 to 533 K (70° to 500° F) and for the high-speed tool steels from 294 to 811 K (70° to 1000° F). The α's and β's from reference 1 for these materials are shown in table I.

The objectives of the research reported herein were: (1) to determine whether the equation developed in reference 1 was applicable to a broader range of materials such as modified AISI 440-C (14-4-1), ausformed M-50, Matrix II, and WD-65; (2) to investigate the relative hot hardness capabilities of Super Nitralloy (5Ni-2Al, a nitriding steel); and (3) to compare the hot hardness characteristics of the nitrided material to those of the high-speed tool steels and AISI 52100. These objectives were accomplished by testing each material for hardness from room temperature to 889 K (1140° F). Short-term hot hardness measurements were obtained with a standard hardness tester fitted with a low oxygen environment electric furnace. All specimens for each material were made from a single vacuum-melted ingot.

TABLE I. - TEMPERATURE PROPORTIONALITY FACTORS

α AND EXPONENTS β FOR AISI 52100 AND HIGH-SPEED

TOOL STEELS FROM REFERENCE 1

$$\left[(Rc)_T = (Rc)_{RT} - \alpha \Delta T^{\beta}\right]$$

Material	α		β	
	K	^{o}F	K	^{o}F
AISI 52100	9.2×10^{-4}	3.4×10^{-4}	1.6	1.6
AISI M-1, AISI M-50, Halmo, and WB-49	1.3×10^{-3}	5.4×10^{-4}	1.4	1.4

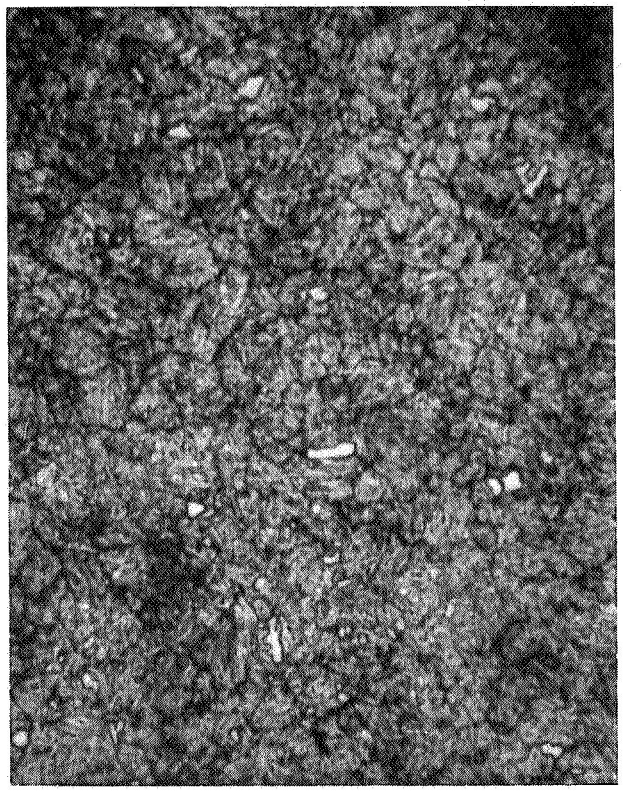
TEST SPECIMENS

The materials used in this investigation were all consumable electrode vacuum-melted (CVM). They were ausformed AISI M-50, modified AISI 440-C (14-4-1), Matrix II, WD-65, and a case hardened Super Nitralloy (5Ni-2Al). The chemical compositions of these materials are presented in table II. Photomicrographs of the individual materials are shown in figure 1. Each of the photographs shows that the structure of the materials tested is typical for these alloys. All specimens for each material were made from one vacuum-melted ingot. The specimens were heat treated according to the heat treat schedules contained in table III.

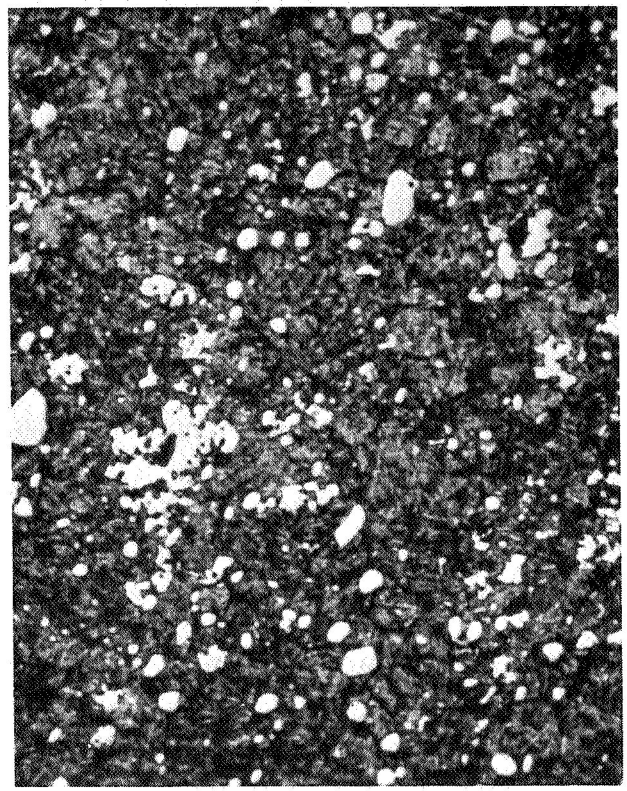
TABLE II. - CHEMICAL COMPOSITION OF MATERIALS

Material	Alloying element, percent by weight (balance Fe)											
	C	Si	Mn	S	P	W	Cr	V	Mo	Co	Ni	Al
Ausformed M-50	0.82	0.17	0.28	0.006	0.011	----	4.12	0.99	4.48	----	----	----
Modified AISI 440 C (14-4-1)	1.14	0.31	0.44	0.009	0.012	----	14.24	1.13	4.01	----	----	----
WD-65[a]	1.10 to 1.15	----	[b]0.15	[b]0.15	-----	2.00 to 2.50	13.50 to 14.50	2.50 to 3.00	3.75 to 4.25	5.00 to 5.50	----	----
Matrix II	0.57	0.22	0.026	0.021	0.008	1.02	3.86	1.00	5.07	7.82	----	----
Super Nitralloy[a]	0.20 to 0.25	0.10 to 0.35	0.25 to 0.45	[b]0.025	[b]0.025	----	0.40 to 0.60	0.07 to 0.15	0.20 to 0.30	----	4.75 to 5.25	1.85 to 2.25

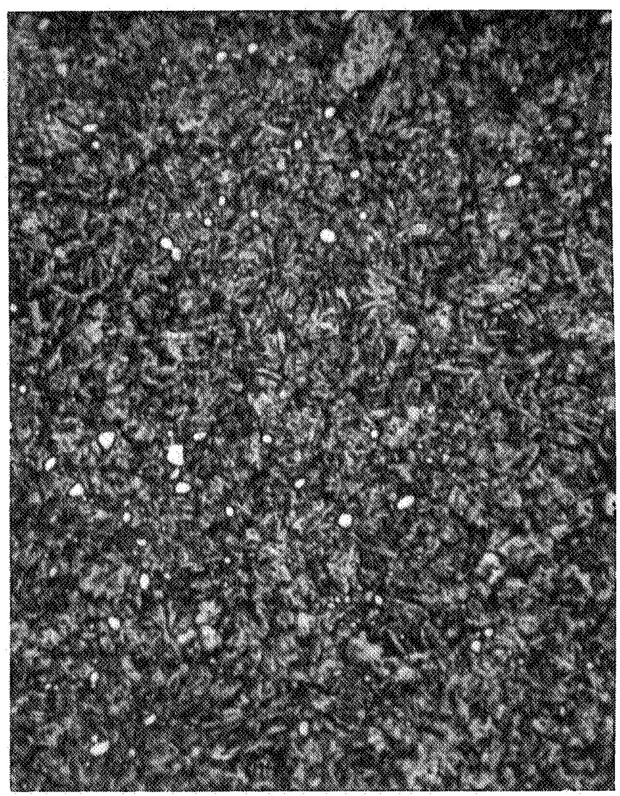
[a]Nominal composition for this material.
[b]Maximum.



(a) Ausformed AISI M-50. Etchant, 2 percent nital.

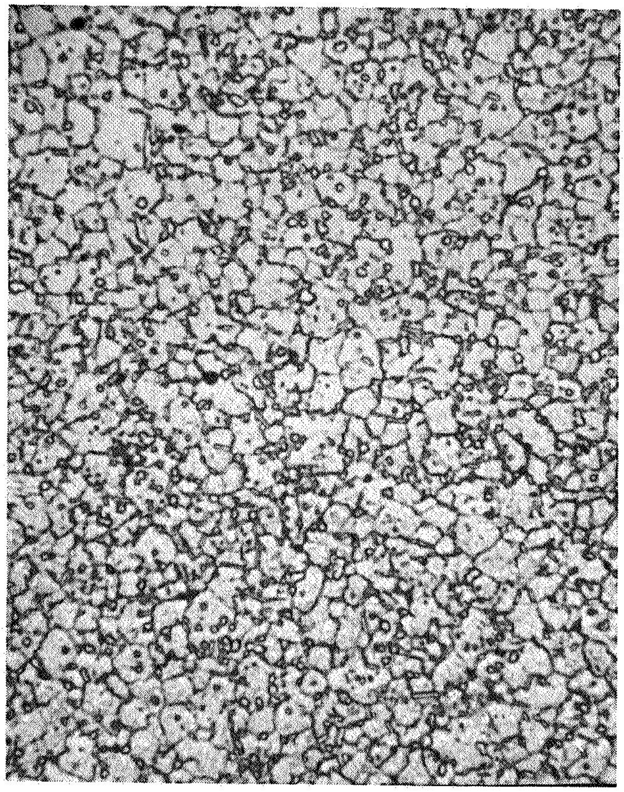


(b) AISI 440-C. Etchant, 2 percent nital.

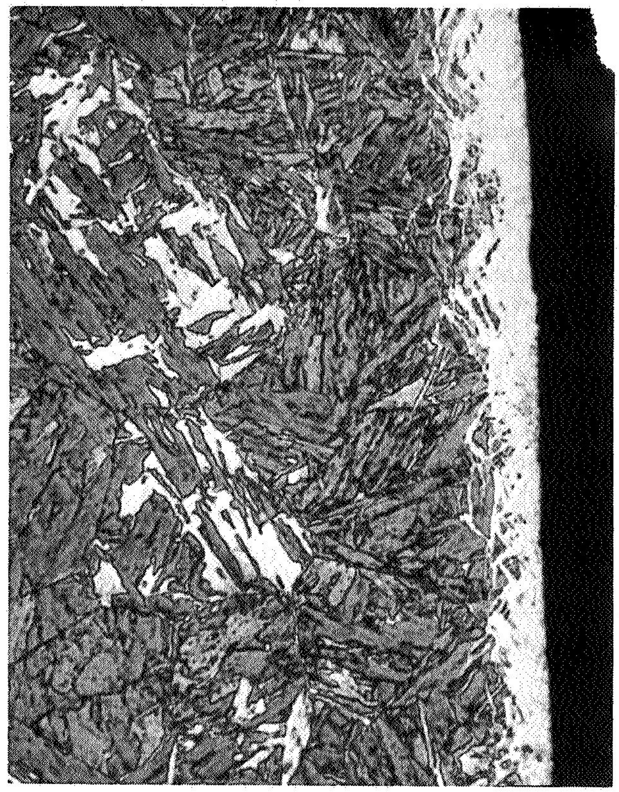


(c) Matrix II. Etchant, 2 percent nital.

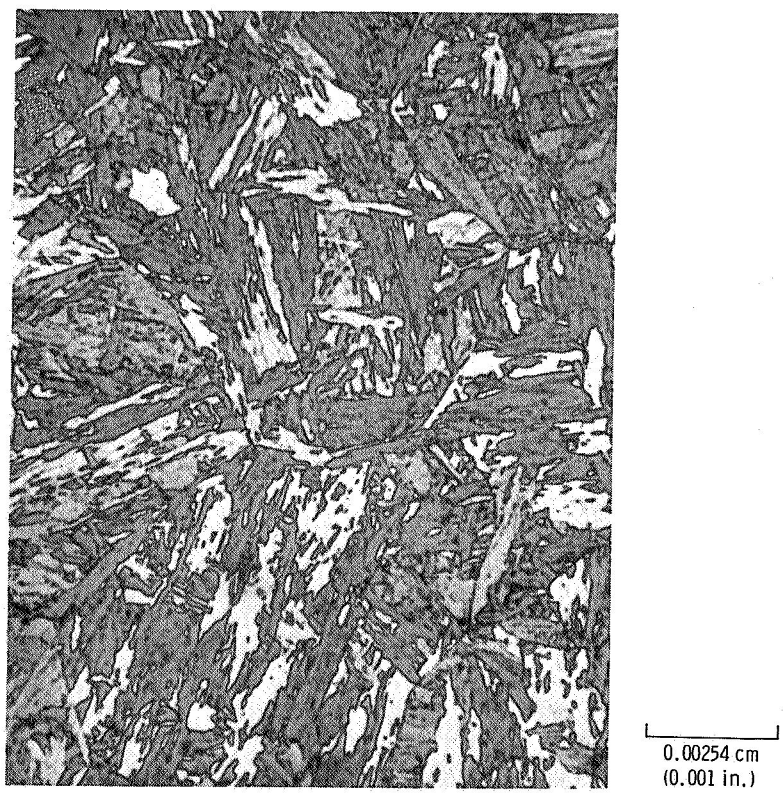
Figure 1. - Photomicrographs of test specimens.



(d) WD-65. Etchant, ferric chloride.



(e) Super Nitralloy case. Etchant, 2 percent nital.



(f) Super Nitralloy core. Etchant, 2 percent nital.

Figure 1. - Concluded.

TABLE III. - TEST MATERIAL HEAT TREATMENT

(a) SI units

Material	Heat treatment temperatures, K								
	Preheat	Austenitize	Quench	Subzero cooling	First temper	Subzero cooling	Second temper	Subzero cooling	Third temper
Ausformed M-50	(30 min) 1089	(30 min) 1420	Air: 1059 Stabilize 5 min Ausform Oil: 339 Air: 297	-----	(2 hr) 797	(1 hr) 200	(2 hr) 797	-----	-----
Modified 440-C (14-4-1)	(30 min) 1089	(30 min) 1420	Oil: 366 Air: 297	-----	(1 hr) 422	(1 hr) 200	(2 hr) 797	-----	(2 hr) 797
WD-65	-------	(4 min) 1478	Oil: 297	(1 hr) 200	(1 hr) 811	(1 hr) 200	(1 hr) 811	(1 hr) 200	(2 hr) 811
Matrix II	(30 min) 1159	(5 min) 1392	Salt: 811 Air: 297	-----	(3 hr) 783	-----	(3 hr) 783	-----	-----
Super Nitralloy	-------	(2.5 hr) 1172	Oil: 297	-----	(5 hr) 963	-----	(2 hr) 950	-----	(60 hr) 797 to 811 Nitride

(b) U.S. Customary units

Material	Heat treatment temperatures, $^{\circ}F$								
	Preheat	Austenitize	Quench	Subzero cooling	First temper	Subzero cooling	Second temper	Subzero cooling	Third temper
Ausformed M-50	(30 min) 1500	(30 min) 2100	Air: 1500 Stabilize 5 min Ausform Oil: 150 Air: 750	-----	(2 hr) 975	(1 hr) -100	(2 hr) 975	-----	-----
Modified 440-C (14-4-1)	(30 min) 1500	(30 min) 2100	Oil: 200 Air: 75	-----	(1 hr) 300	(1 hr) -100	(2 hr) 975	-----	(2 hr) 975
WD-65	-------	(4 min) 2200	Oil: 75	(1 hr) -100	(1 hr) 1000	(1 hr) -100	(1 hr) 1000	(1 hr) -100	(2 hr) 1000
Matrix II	(30 min) 1625	(5 min) 2050	Salt: 1000 Air: 75	-----	(3 hr) 950	-----	(3 hr) 950	-----	-----
Super Nitralloy	-------	(2.5 hr) 1650	Oil: 75	-----	(5 hr) 1275	-----	(2 hr) 1250	-----	(60 hr) 975 to 1000 Nitride

APPARATUS AND PROCEDURE

Samples were prepared for hardness testing by sectioning with a cutoff wheel and then grinding flats with a belt grinder. Both sectioning and grinding were done by hand with a copious supply of coolant to prevent overheating of the test specimens. The hardness of the material was measured at both room and elevated temperature using a standard hardness tester fitted with a low oxygen environment electric-resistance furnace (fig. 2). The low oxygen environment was used to eliminate any possible effect of surface oxidation and decarburization on the hardness measurements. Large size dial indicators were fitted to the hardness tester so that readings to the nearest tenth of a Rockwell C point could be made without interpolation. Rockwell C hardness tests were performed using a 150-kilogram load with a Rockwell C diamond indenter on all through hardened materials and on the core material of the Super Nitralloy.

Rockwell A (Ra) hardness tests were performed using a 60-kilogram load with a Rockwell C diamond indenter on the nitrided case of Super Nitralloy. These readings were then converted to Rockwell C (Rc) values. Since the indenter penetration was less than 10 percent of the case depth, the core hardness will not have any effect on the case hardness measured in this way.

Hardness measurements were taken immediately after reaching an equilibrium temperature and before the heat input was increased for the next higher temperature. Ap-

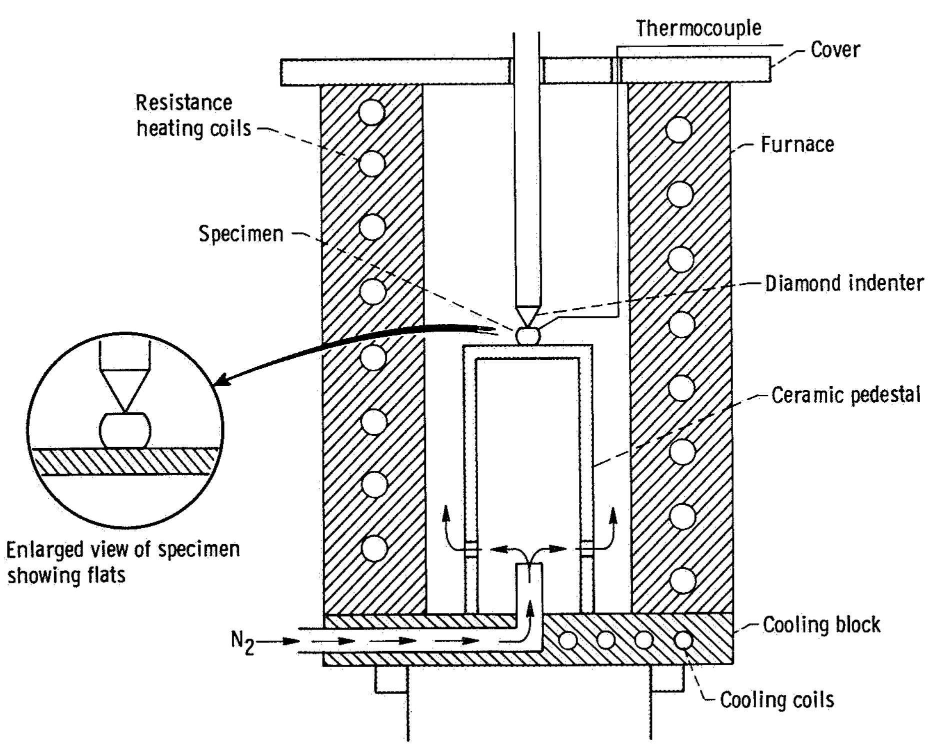


Figure 2. - Cross section of hot hardness tester.

proximately 30 minutes was required to reach equilibrium. A minimum of two hardness measurements was taken for each material at each temperature.

RESULTS AND DISCUSSION

Hot hardness measurements were made for specimens of ausformed AISI M-50, a modified AISI 440-C (14-4-1), WD-65, Matrix II, and the case and core of Super Nitralloy (5Ni-2Al). All of the specimens of each material tested were from one consumable electrode vacuum-melted ingot. The results of these measurements are shown in figures 3 and 4. The data of figure 3 suggests that, regardless of the material, the hot hardness of the individual materials show the same functional dependance on temperature. To verify this observation, the change in hardness, ΔRc (hardness at room temperature minus hardness at test temperature) was plotted in figure 5 as a function of temperature. This had the effect of normalizing each material to the same room temperature hardness.

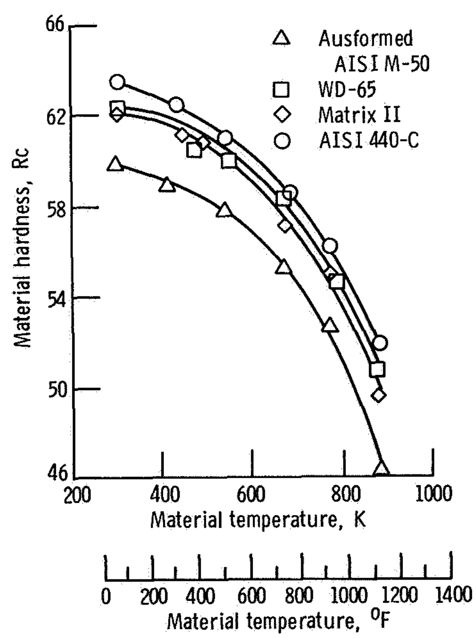


Figure 3. - Short-term hot hardness of ausformed AISI M-50, WD-65, Matrix II, and modified AISI 440-C as a function of temperature.

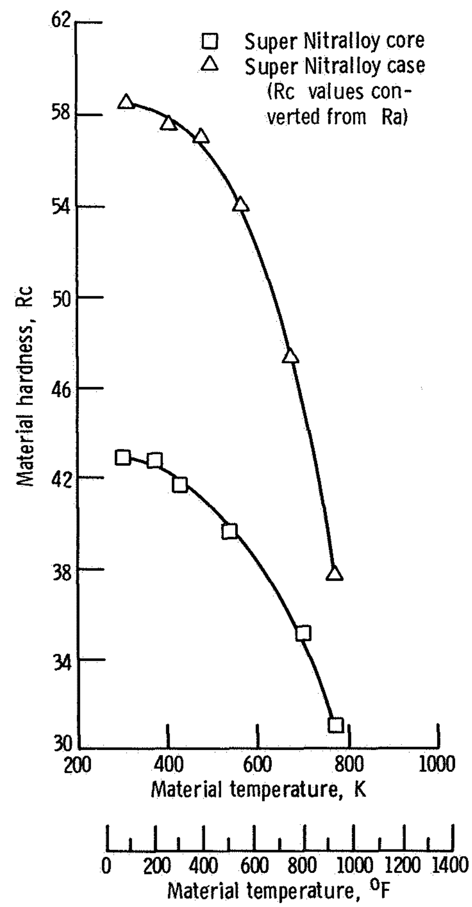


Figure 4. - Short-term hot hardness as a function of temperature for Super Nitralloy case and core.

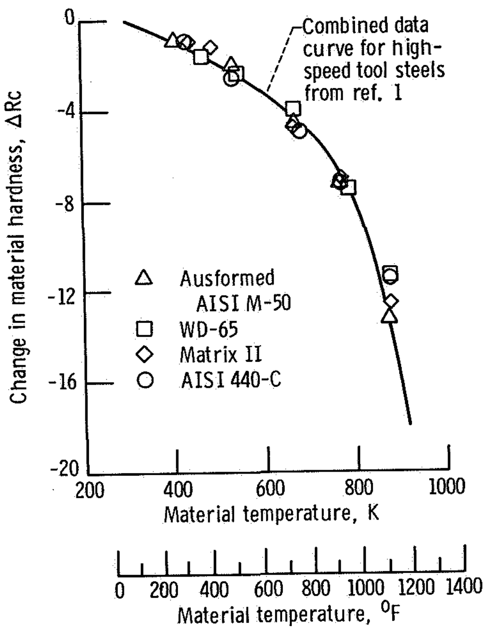


Figure 5. - Normalized short-term hot hardness as a function of temperature for ausformed AISI M-50, WD-65, Matrix II, and modified AISI 440-C.

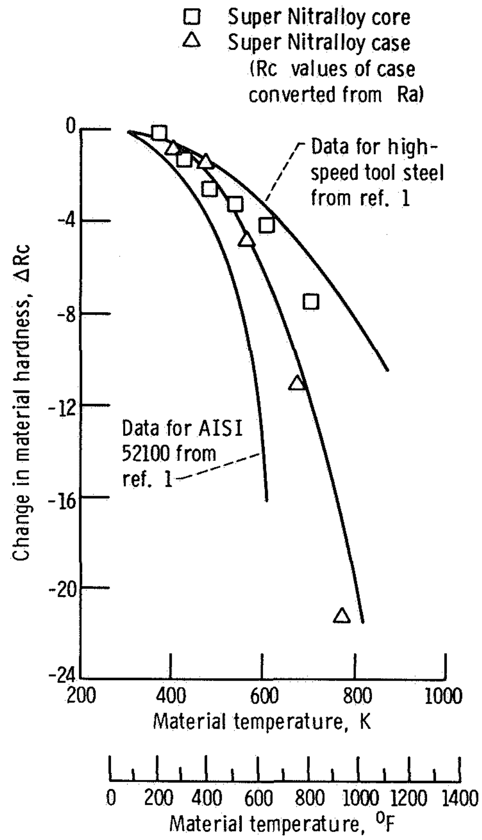


Figure 6. - Normalized short-term hot hardness of Super Nitralloy case and core as a function of temperature compared with previous data for high-speed tool steel and AISI 52100.

For comparison purposes, the combined high-speed tool steel data curve from reference 1 is also shown. These data show that the changes in hardness with increasing temperature of ausformed AISI M-50, modified AISI 440-C (14-4-1), WD-65, and Matrix II are independent of initial room temperature hardness and material composition. These changes satisfy the equation form developed in reference 1 for the prediction of hardness with temperature,

$$(Rc)_T = (Rc)_{RT} - \alpha \, \Delta T^{\beta}$$

Thus, if the room temperature hardness of any of these materials tested herein is known, the hardness at the operating temperature can be predicted within one point Rockwell C.

The data of figure 4 for Super Nitralloy were also normalized by plotting the change in hardness $\left[(Rc)_T - (Rc)_{RT}\right]$, as a function of temperature in figure 6. These data were compared with the normalized data curves for high-speed tool steels and AISI 52100, from reference 1. These data show that the normalized loss of hardness with tempera-

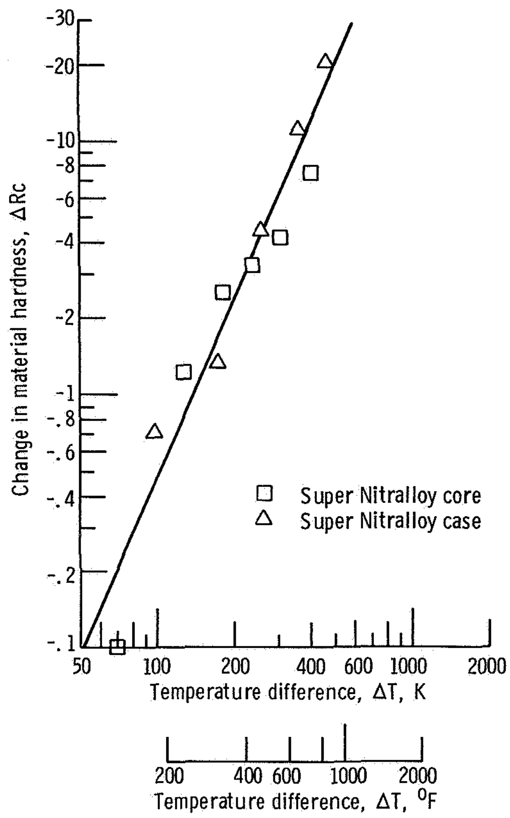


Figure 7. - Normalized short-term hot hardness of Super Nitralloy as a function of temperature difference.

ture of both the case and core of Super Nitralloy is superior to AISI 52100 but inferior to the high-speed tool steels.

The Super Nitralloy data of figure 6, when plotted on log-log coordinates in figure 7, can be represented as with the tool steels by a linear function in log ΔRc and log ΔT. For the Super Nitralloy case between 294 and 769 K and for the core between 294 and 600 K

$$\Delta Rc = -1.272 \times 10^{-5} \, \Delta T^{2.287}$$

Substituting from the previous equation for ΔRc

$$\Delta Rc = (Rc)_T - (Rc)_{RT}$$

results in

$$(Rc)_T = (Rc)_{RT} - 1.272 \times 10^{-5} \, \Delta T^{2.287}$$

Similarly for the Super Nitralloy case between 294 and 769 K (70° and 925° F) and for the core between 294 and 600 K (70° and 620° F)

$$\Delta Rc = 3.316 \times 10^{-6} \, \Delta T^{2.287}$$

The general form of the equation is identical to that of the equation developed for the high-speed tool steels and AISI 52100 in reference 1. The Super Nitralloy case and core are precipitation hardening alloys (refs. 2 to 4). As the temperature of this material is raised, it begins to overage and soften. When the operating temperature nears the tempering temperature, this process is accelerated and the hardness decreases more rapidly. As the test temperature is raised beyond the tempering temperature, the precipitation hardening precipitate particles increase in size and decrease in number and the material begins to spheroidize (ref. 5). At this point, the greatest decrease in hardness occurs and the hardness of the material tends to decrease toward the fully annealed condition.

The difference in hot hardness capability between the Super Nitralloy case and core, the high-speed tool steels, and AISI 52100 can be partially explained by the difference in the precipitation hardening phase. In AISI 52100, the precipitate is an iron carbide ($Fe_{2.4}C$) called epsilon carbide. In the high-speed steels the precipitates are W_2C and/or Mo_2C (ref. 6). The precipitate in the Super Nitralloy case is AlN, while that of the core is AlNi (refs. 2 to 4).

It would be expected that all materials which obtain their hot hardness from the precipitation of W_2C, VC, or Mo_2C would have hot hardness characteristics similar to those shown by the high-speed steels to 812 K (1000° F). The materials which obtain their hot hardness from the precipitation of the epsilon carbide would be expected to have the same hot hardness characteristics as AISI 52100 up to 450 K (350° F). Those that obtain their hot hardness from the precipitation of AlN or AlNi would be expected to have the same hot hardness characteristics as the Super Nitralloy case and core up to 769 K (925° F). However, since the tempering temperature for the AlN, AlNi, W_2C, Mo_2C, and VC are approximately the same, the difference between the Super Nitralloy and high-speed tool steels cannot be explained strictly by the type of precipitate. Here the metallurgical microstructure (size of precipitate, distribution, and coherency) becomes significant.

In this study, the materials tested were exposed to elevated temperatures only long enough to make hardness measurements after having reached a predetermined equilibrium temperature (approximately 30 min). The effects of exposure to elevated temperatures for longer periods of time were not studied as a part of the research reported herein. However, time at temperature is a factor as important as temperature itself with regard to hot hardness characteristics. In fact, in heat treating practice, these two factors are considered interchangeable. That is, if the heat treating temperature is reduced, an identical structure can be obtained by increasing the exposure time at the lower temperature.

The hardness tests for the Super Nitralloy case were made with a 60-kilogram load and read on the Rockwell A scale. These readings were converted to Rockwell C. The average case depth of the Super Nitralloy tested was 0.051 centimeter (0.020 in.). The penetration depth of the indenter was less than 0.0051 centimeter (0.002 in.). According to standard hardness testing procedure, when penetration of this indenter is less than 10 percent of the total case depth, there should be no effect of the core hardness (ref. 7). As a result, it can be concluded that no loss of accuracy in the hardness measurement of the case was incurred.

SUMMARY OF RESULTS

Short-term hot hardness studies were performed with ausformed AISI M-50, Matrix II, WD-65, a modified AISI 440-C (14-4-1), and case hardened Super Nitralloy. Hardness levels of each material were measured at elevated temperatures in an electric furnace with a low oxygen environment. Test temperatures ranged from 294 to 877 K (70° to 1120° F). The following results were obtained:

1. The hot hardness characteristics of the ausformed AISI M-50, Matrix II, WD-65, and modified AISI 440-C were the same as for those determined for high-speed tool steels. Hot hardness for these steels can be predicted within one point Rockwell C.

2. The hot hardness characteristics of both the case and core of the Super Nitralloy fall between those of AISI 52100 and the high-speed tool steels.

3. The short-term Rockwell C hardness at temperature for the Super Nitralloy material between 294 and 769 K (70° and 925° F) can be predicted within one point Rockwell C.

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National Aeronautics and Space Administration,
and
U.S. Army Air Mobility R&D Laboratory,
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16. Abstract

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